ANALYSIS OF LARGE ARRAY SURFACE MYOELECTRIC POTENTIALS FOR THE LOW BACK MUSCLES

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Abstract-**An algorithm was developed and tested for the ability to differentiate between the spatial distribution of large arrays of acute and normal recordings of surface electromyographic (EMG) data from subjects with and without low back pain (LBP). The surface EMG data from 62 channels were statistically analyzed and the spatial distribution of the root mean square (RMS) values were used in a multivariate quadratic discriminant model to classify the healthy and acute LBP subjects. The surface EMG distribution from the low back of 161 healthy and 44 acute LBP subjects were collected in three minimum stress postural positions including standing, 20 degrees of lumbar flexion and standing with arms extended forward holding 1.36 kg (3 lbs.) of weight in each hand. The best results obtained from the 'flexion' group of experiments correctly reclassified 95.5% (42 of 44) of the acute subjects and 99.4% (160 of 161) of the healthy. The success rate of this reclassification were found to be superior to reported patient classifications based on smaller set of electrode pairs using fewer subjects. The results indicated a potential of the model for clinical patient classification.**

Keywords **- Myoelectric potential distribution, Low back pain, Surface electrodes, Patient classification**

I. INTRODUCTION

Low back pain (LBP) is a major economic health care problem in the United States. The general annual prevalence of LBP is 15 to 20 thousand and a lifetime prevalence of approximately 80 thousand per 100 thousand people in the population [1]. Back problems are the most frequent cause of limitation of activity in people less than 45 years of age [2] and is the most expensive industrial injury, causing up to 25% of all workers' compensation claims. Lost time from work in addition to disability payments and medical costs related to LBP have been estimated to cost more than $50 billion annually [3]. Using currently available techniques in as many as 80% of patients with acute LBP, the precise anatomic source of the pain cannot be localized [4].

Recently, technical advances in microelectronics and computer science have improved signal processing, sensitivity and simultaneous multiple site data collection methods essential to the clinical efficacy of surface EMG. In fact, the position of the American association of electrodiagnostic medicine in 1996 was anticipating surface EMG improvements with specialized computer signal processing to "prove clinically useful in the noninvasive monitoring of the progression of a nerve or muscle disorder."[5] taking advantage of the new instruments, recent activity in surface EMG research has been focused on the parameters to characterize the muscular component of low back pain. It was found that the left to right side imbalance of the median frequency of surface EMG reflects changes in the activation of lumbar muscles associated with the presence of pain. Furthermore, in chronic LBP the changes may reflect long term effects of subtle postural adjustments resulting from a strategy to avoid sensation of pain [6]. In another study multivariate discriminant analysis of mean frequency parameters from six channels of surface EMG signals were used to develop an algorithm for classifying persons into LBP and control groups. The study required large force exertions with low back muscles up to maximum voluntary contractions. Subjects with LBP were identified with 92% accuracy and controls with an accuracy of 83% [7]. The analytical power of multichannel surface EMG technology has been further increased by an instrument developed by the Paraspinal Diagnostic Corporation (PDC) of Columbus Ohio. This instrument, referred to as the Computerized Electromyographic Reconstruction of Spinal Regions (CERSR) employs 63 electrodes in a 7 by 9 array of 62 referenced to one common.

The electrode array captures the surface distribution of the myoelectric potentials and through analog to digital conversion a computerized reconstruction of the myoelectric activity of the underlying muscles is accomplished. From each electrode output, the root mean square or RMS amplitude of the surface EMG is calculated and stored for further analysis and produce a colorized visual display of the potentials from the paraspinal and other muscles of the low back.

Although the 62 channel signal display provides an impressive visual discrimination between the normal and abnormal EMG activity patterns, further quantification of the RMS data is needed for precise classification of signal distributions.

The purpose of this study was to develop a classification for differentiating between the 62 channels of surface EMG data obtained with the CERSR system from patients with acute LBP and subjects without LBP. The focus was to demonstrate the feasibility of constructing an algorithm which can differentiate between spatial distribution of RMS values obtained from the low back region of the subjects.

Specifically, the surface EMG data, obtained during the performance of three different tasks, were analyzed independently to determine which task produced the best information to differentiate between healthy and acute LBP subjects.

II. METHODOLOGY

1) *Subjects:* A retrospective analytical study was conducted on surface EMG data collected by the CERSR system from healthy subjects and patients with LBP in two different settings. The classification algorithm was designed and trained to differentiate between normal and abnormal surface EMG patterns. A combined set of EMG data was obtained form volunteer workers employed at the offices of the Nationwide Insurance Company (healthy group) and the patient populations of the occupational health clinics affiliated with the Ohio State University Medical School (acute LBP group). Surface EMG data from 62 channels and health status reports were obtained

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Abstract

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from subjects using identical protocol at each site.

Volunteers and patients were asked to complete a questionaire requesting demographic and medical history information including the visual analog pain score. Excluded from the study were individuals with a history of spine surgery, radiculopathy, serious back conditions of tumor, infection or herniated disk, diabetes and thyroid disorders. Volunteer workers at the Nationwide Insurance Co., who reported experiencing any LBP in the past 12 months, were excluded. Also excluded were patients from the Ohio State University group who reported disabling low back pain, which occurred between 6 weeks and 6 months prior to beginning the study. Included in the study were both male and female individuals of any race 18 years or older without LBP and with either work related or non-work related acute LBP of less than 6 weeks duration. All subjects signed the informed consent document before entering the study. Participation by the acute LBP patients required the approval of their primary care physician to assure no treatment interference from the research protocol. Surface EMG and demographic information including age, gender, body weight and height was collected form 205 participants at the two locations. At the Nationwide Insurance Co., 161 working volunteers were tested. Forty-four acute LBP patients were similarly tested at Ohio State University. Further data was also collected from the patients concerning their date and mechanism of injury, work status and the results of their physical examination. Subjects in the acute LBP groups were able to perform every day tasks with pain, while receiving medical care as deemed appropriate by the treating physician.

2) Instrumentation: The CERSR instrument is a Windows based NT operating system with a Pentium II central processing unit containing a 64 channel analog to digital converter. The surface myoelectric potentials are collected form a fixed 7 columns by 9 rows array of 63 pre-gelled, silver-silver chloride electrodes referred to one common electrode located in the center of the array. The 1.0 cm diameter electrodes are spaced 3.0 cm apart center to center and attached to a thin plastic flexible film pre-coated with a thin skin contact adhesive. The skin adhesive and the film is to hold the electrode array in place on the subjects low back region during the EMG data collection. The array of discrete electrodes covered a 19.0 cm by 24.5 cm skin area.

Each electrode in the array is sampled 2000 times per second at a frequency bandwidth of interest between 30 to 150 Hz, with a differential mode gain of 88.0 $\pm$ 0.5% for each channel. The common mode rejection ratio for any channel with respect to the reference electrode is 80 dB or greater at 60 Hz. Input impedance of any channel is greater than 10,000 megaohms in parallel with 20pF and the output impedance of each channel is less than 200 ohms.

With each electrode input connected to ground the total self generated voltage noise, referred to the input, does not exceed 0.05 mV RMS on any channel. Cross talk between neighboring channels is less than 1%.

Potentials from the muscles of the low back were recorded in real time. The RMS voltage of the EMG signal was calculated for 1 second duration for each adjacent electrode referenced to the common. The color coded RMS values of EMG signals are displayed on the computer monitor, superimposed on a drawing of the subject's skeletal anatomy. The EMG image display contains 63 dots, one for each electrode in the array and 206 nearest neighbor electrode pair combinations represented by colored bars connecting the adjacent electrodes on the image. The color of each bar is proportional to the RMS value between adjacent electrodes. Using a 264 color spectrum, the electrode pair with the highest RMS value is indicated in red and the electrode pair with the lowest RMS value in blue. The remaining electrode pairs are assigned colors in between red and blue. The resulting RMS voltage gradient display is an image representing the distribution of myoelectric activity of the muscular anatomy adjacent to the electrode array.

3) *Data collection:* Sequential recording or scans of surface EMG data was collected form 62 channels from the low back regions of all participating subjects, using a standardized protocol during each of three postural tasks. The three tasks, representing increasing levels of minimal low back stress were: standing upright, standing with 20 degrees of lumbar flexion and standing upright with arms extended forward holding a 1.36 kg (3 lbs.) weight in each hand. In this standardized protocol, which all subjects in both groups completed, the subjects were standing as follows: in the upright standing position, subjects stood at ease, feet shoulder width apart, arms at the sides. In the flexed position, subjects stood as before with 20 degrees of anterior trunk flexion as measured with a goniometer. The goniometer's arms were parallel with the subject's femur and the mid-axillary line. In the weight holding position, subjects again stood as before, while holding a 1.36 kg (3 lbs.) weight in each hand, directly in front of the body at shoulder height, with the elbows extended, wrist rotation in the neutral position and fists closed around the handle of the weights.

The subjects were allowed to wear shoes if the heels were less than 1 inch in height. Women in high heels were asked to remove their shoes.

Three repeated scans of the EMG electrode array were performed at each postural position. The scans were completed and the data was stored digitally for analysis and visual display. Each scan was reviewed for diagnostic quality by inspecting the display for ambiant noise (at 60 Hz) generated "super physiologic" power value. This was confirmed by observing the frequency distribution on the fast Fourier transform of the suspect channel with the 60 Hz software filters turned off. If the 60 Hz peak exceeded 100 mV RMS on a suspect electrode than the electrode was reapplied, the scan was eliminated from the series and another scan was collected. For data analysis a single scan from each postural task was used for each subject. The scan was chosen by the technician, based on the consistency and quality of recording.

4) *Placement of electrodes:* Participants were asked to uncover their low back for the placement of the 7 by 9 electrode array supplied with conductive paste and fastened to a non-allergenic thin plastic sheet. The superior portion's of the iliac crest of the participants were palpated bilaterally and the separation between them measured. The skin was marked at half the distance between them and from this mark the distance was also measured vertically to the spinous process of the T-7 vertebra. The center or reference electrode in the array was then positioned 6 cm above the mark and the electrode array was

spread smoothly over the low back region of the subject and applied at once to be held in place by the skin adhesive. The measured distances in centimeters were entered into the software which scaled the electrode array and EMG output image to correspond to the subjects size and anatomy.

5) *Classification model:* The model was developed based on the demographic and surface EMG data obtained from healthy volunteers and patients with acute LBP and their self determined categorization of health. The model was used to classify the subjects into healthy or acute LBP groups and the results contrasted with their self determined categorization. It is acknowledged that this methodology is assuming that the self categorization is the 'gold standard' and the uncertainty and limitations associated with this assumption is fully recognized.

The algorithm of the classification model was based upon a quadratic discriminant function. This function calculated the n-dimensional mean or centroid of each group and thus separated the n-dimensional space into two regions. The classification of new subjects was determined by their nearness to the centroid of the respective group [8]. The model assumes a multi variate Gaussian distribution for the chosen predictors and plots of the data support this assumption. Furthermore, the model allowed us to calculate the posterior probability of membership in each of the two groups and this may be considered as a surrogate for "low back pain intensity" on a scale of 0-1. For example, a probability of 0.9 of belonging to the acute group indicates a high level of pain whereas a 0.1 probability of membership in acute group indicates minimal to no pain. The specific details of the algorithm are proprietary and are not presented here.

III. RESULTS

The demographic characteristics of the study population are shown on Table I.

Summary statistics were computed for the 62 pairs of electrodes along with body mass index, body weight and height (65 variables total) separately for the three postural tasks. Data from the healthy and the acute groups were compared by performing t tests for all 65 variables. Variables with p values less than 0.1 (based upon t test) were chosen as potential predictors to discriminate between the two groups. This relatively high level of significance was chosen to guard against the possibility of excluding the marginally significant predictor variables.

In terms of body weight, height and body mass (BMI), significant differences were found between the acute LBP and healthy subjects. The body weight of female subjects and the body weight and BMI of male subjects were significant predictors to differentiate between the acute and healthy groups ($p<0.05$) in the upright standing and in the flexion tasks. For reasons of incomplete data sets four subjects had to be excluded from the weight holding group. Two females and one male in the acute LBP group and one male in the healthy group were not included in the data analysis.

The number of significantly different ($p<0.1$) variables found in each postural task is shown in Table II.

To accomplish anatomic symmetry between the left and right side low back muscles, additional electrode variables were added to the model as needed. In the 'Upright' group none, in the 'Flexion' group 3 and in the 'Weight Holding' group 5 additional electrode variables were included as indicated in Table II. Each added electrode location in the array is indicated by row and column number respectively.

Using the model we re-classified the subjects into the acute and healthy groups and calculated the posterior probability of the subject belonging to each group. The results of the analytical re-classifications are shown on Table III.

The values in parenthesis are the mean posterior probabilities of belonging to the respective groups. These probabilities are referred to as posterior since they are calculated from the observed data but here after will be called simply probability. Conceptually the posterior probability can be viewed as an index of LBP severity. The visual analog pain score available from the patients with acute LBP was not used in the analysis during this study. The focus was primarily on the development of the classification model. In a future study the correlation of the pain score with the probability of belonging to a subject group will be addressed.

These preliminary results indicated the flexion data to be most promising in terms of classifying subjects into acute LBP or healthy groups. The holding and upright data sets also produced reasonably good results but had difficulties distinguishing between healthy and acute. This may be due to the "truth" of some healthy or the absence of LBP from acute subjects at the time of the surface EMG data was collected. The best results obtained from the 'Flexion' group of experiments correctly reclassified 95.5% (42/44) of the acute subjects and 99.4% (160/161) of the healthy ones. It should be noted, however, that the algorithm is reclassifying the same data upon which it was trained and ideally an external validation data set should be used. Furthermore, a high probability associated with an incorrect classification merits further investigation of the data or the patient's self categorization.

TABLE I
DEMOGRAPHIC COMPARISON OF ACUTE LBP AND HEALTHY SUBJECTS
[Mean (SD)]

Groups	N	Age years	Weight kg	Height cm	BMI kg/m^2
FEMALE					
Acute LBP	18	35.2 (9.9)	85.7 (23.0)	168.2 (9.1)	30.1 (6.5)
Healthy	86	39.5 (11.5)	71.0 (16.1)	165.0 (6.6)	26.2 (6.0)
F value		NS	0.0333	NS	NS
MALE					
Acute LBP	26	35.0 (8.0)	90.6 (19.8)	176.1 (7.8)	29.2 (5.6)
Healthy	75	39.1 (9.4)	86.6 (13.6)	180.0 (7.3)	26.8 (3.7)
F value		NS	0.0143	NS	0.0065

TABLE II
VARIABLES USED FOR THE QUADRATIC DISCRIMINANT FUNCTION ANALYSIS

	Significantly different ($p<0.1$) variables	Electrodes added to gain left to right symmetry
Upright	9 electrodes weight, BMI	None
Flexion	27 electrodes weight, BMI	3 electrodes [v43, v61, v81]
Holding	12 electrodes weight, BMI	5 electrodes [v46, v56, v64, v73, v81]

TABLE III
RE-CLASSIFICATION RESULTS OF ACUTE LBP AND HEALTHY GROUP OF SUBJECTS BASED ON MULTICHANNEL SURFACE EMG DATA FROM 3 POSTURAL CONDITION

From Status	To Status (%subjects classified)					
	Upright		Flexion		Holding	
	Acute	Healthy	Acute	Healthy	Acute	Healthy
Acute	22.7	77.3	95.5	4.5	68.3	31.7
	(0.980)*	(0.980)	(0.945)	(0.596)	(0.944)	(0.833)
Healthy	0.6	99.4	0.6	99.4	4.4	95.6
	(0.780)	(0.990)	(0.691)	(0.997)	(0.695)	(0.967)

* In parenthesis are the mean probabilities of belonging to the re-classified group.

IV. DISCUSSION

Quadratic discriminant functional analysis was used to develop an algorithm, applied to surface EMG data for classifying subjects into low back pain and healthy status. Surface myoelectric potential distribution from subjects standing with flexion was found to be most promising to classify the subjects into healthy and acute low back pain status. The results show 95.5% of the acute and 99.4% of the healthy subjects standing flexed were classified into their respective classes at the probability (calculated from the existing data) of p=0.945 and p=0.997 respectively. These results indicate significant potential for this model to be used for patient classification. The success rate of reclassification were found to be superior to the published literature for the classification of LBP patients.

Data from the acute and healthy subjects standing upright and holding weight also produced reasonable results but had more difficulty to distinguish between healthy and acute LBP status. There were 99.4% of the healthy subjects classified to be healthy using the upright data and 95.6% of the healthy subjects were classified to be healthy using the weight holding data. Of the acute subjects, 77.3% were classified healthy and only 22.7% acute using the upright data. From the acute group 68.3% was classified acute (p=0.944) using the weight holding data. The remaining 31.7% however were classified incorrectly healthy but at an also high probability of p=0.838. The high probability of incorrect assignment merit further investigation of the data or the clinical classification. The "truth" of some of the acute data or the absence of low back pain in the healthy subjects need to be verified at the time of collection of the surface myoelectric potentials.

V. CONCLUSION

The results of this work indicated a significant potential for this technique and methodology since the success rates of reclassification are superior to published literature on the classification of LBP patients. However, there is also a need to collect and analyze more data using the CERSR instrumentation and further test the existing classifying algorithm with well defined clinically confirmed LBP status. The data collection protocol should be selected to assure reliability and repeatability, confirm the state of pathology in the patients and use constant time periods and exact treatment protocols. The refinement will be fundamental to the classification methodology leading to acceptance and use in regular clinical practice.

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